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Hydrogeology of the Zama-Bistcho Lakes Area, Alberta

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ABSTRACT

The Zama-Bistcho Lakes map area, in northwestern Alberta, shares common boundaries with the province of British Columbia to the west and with the Northwest Territories to the north. Elevations range from less than 330 m (1100 ft) to about 830 m (2370 ft). The main discharge area is in the Zama-Hay Lakes lowland. The map area has several prominent hills: those found along the southern part of the map area, the unnamed ridge north of the town of Rainbow Lake, the Bootis Hill to the northwest, the unnamed hills south of Bistcho Lake, and the Cameron Hills to the northeast.

Groundwater potential in the surficial sediments is fair to excellent, both in terms of quantity and quality. Upper Cretaceous bedrock sediments are mainly shales, which are poor aquifers. Lower Cretaceous sediments, in particular the Bluesky-Gething Formation, have saline waters. Groundwater potential of the Paleozoic sediments is unknown, except that they contain saline waters.

INTRODUCTION

The Zama-Bistcho Lakes map area covers two NTS map sheets (NTS 84L and 84M). The area lies in the northwest corner of Alberta between longitudes 118° and 120° west and latitudes 58° and 60° north, sharing common boundaries with the Northwest Territories to the north and British Columbia to the west. The map area covers approximately 25 000 km^2 (9800 sq mi). Of the three small communities in the area, the existence of Rainbow Lake and Zama City is related to nearby oil and gas fields; the third, Assumption-Habay, is a small Indian settlement. The area is not farmed. The limited lumbering northeast and southeast of Rainbow Lake is processed at the large lumber mill in High Level, about 50 km (30 mi) east of the map area.

Access to the area is poor; one main gravel road connects the towns of Rainbow Lake and High Level and oil company secondary gravel roads give access to the main oil fields south of Rainbow Lake and to the Zama oilfield north of Assumption-Habay.

PHYSIOGRAPHY AND DRAINAGE

The map area can be divided into three main physiographic regions. The Cameron Hills Upland in the northern one-third of the area includes Petitot River valley to the west, Bistcho Lake in the center, and parts of the Cameron Hills to the east. The Fort Nelson Lowland in the central part of the area includes the Hay River valley to the south, Zama and Hay Lakes in the center, and the Chinchaga River valley in the southeast. The Clear Hills Upland is in the southwestern part of the map area.

Elevations range from less than 330 m (1100 ft amsl) above mean sea level along the Chinchaga River valley in the east-central part of the map area to about 830 m (2730 ft) in the unnamed hills a short distance south of Bistcho Lake. Several prominent topographic highs are found within the map area. The hills in the southern part of the map area reach an elevation of 710 m (2325 ft). A long, narrow, and asymmetrical ridge, with a maximum width of 11 km (7 mi) and a length of about 50 km (30 mi), a short distance south of Zama-Hay Lakes, rises abruptly about 120 m (400 ft) above the lowland of the Zama-Hay Lakes region. The Bootis Hill, in the northwestern portion of the area, rises about 240 m (800 ft) above the Petitot River drainage area. An unnamed series of hills directly south of Bistcho Lake rise about 210 m (700 ft) above the level of the lake. Finally, in the northeast corner of the map area, parts of the Cameron Hills rise gently about 180 m (600 ft) above the level of Lake Bistcho.

Surface water bodies are numerous. The main lakes are Zama-Hay Lakes in the south-central part of the map area, which cover approximately 290 km^2 (110 sq mi), and Bistcho Lake in the northern part, which covers approximately 420 km^2 (160 sq mi).

Of the two main drainage systems in the area, the most extensive is the Hay River-Chinchaga River drainage system in approximately the southern two-thirds of the map area. The drainage of this area is poor; rivers and streams meander sluggishly. The lowlands of this southern drainage system are subject to periodic flooding. One such flooding, after heavy rains in June 1977, washed out the main road to the town of Rainbow Lake in many places and caused intense erosion in many other areas. The Sousa Creek flows towards the north through the Hay Lake Indian Reservation. On June 6, 1977, the creek discharge increased from its usual trickle to a maximum flow of about 67 m^3/s (2400 ft^3/s) (Environment Canada, pers. comm.). The areal extent of Zama-Hay Lakes increased considerably due to the low relief of the surrounding topography. The level of the lake rose to between 331 and 332 m (1085 and 1090 ft) compared with a normal level of less than 328 m (1075 ft). A 16 km (10 mi) portion of the road north of the hamlet of Assumption-Habay was covered by 2 to ~ 5 m (6 to 15 ft) of lake water. At the end of August 1977, a portion of this road was still under water.

The northern drainage system includes Bistcho Lake and the Petitot River. This area is better drained even though the water table is close to the land surface. The Petitot River, which empties into the Liard River in British Columbia, is fast and does not meander; strong erosion was not observed in its vicinity during the fieldwork period. The surficial sediments in the northern drainage system area are definitely thicker and are possibly more permeable than in the southern part of the map area. A few hydrogeological features (springs, ponds, sloughs) were visited in this northern area during the field season. The total dissolved solids in the water of these features suggest that water from Bistcho Lake infiltrates into the surficial sediments to the west of the lake and resurges to form small lakes from which streams originate. These streams eventually empty into the Petitot River a few miles downstream.

CLIMATE

According to Koeppen's classification (after Longley, 1972), the climate of the area is microthermal with the average temperature of the warmest month above 10°C (50°F) and the average temperature of the coldest month below -3°C (27°F). Mean annual precipitation (over a period of 30 years, after Longley, 1972) varies from less than 406 mm (16 in) in the central and southeastern parts of the map area to slightly over 457 m (18 in) in the northwestern and southwestern portions.

Mean annual snowfall is in the order of 1.5 m (60 in) per year. Rainfall records are available only for periods of six to seven months during the time forestry lookout towers were in operation. These records indicate rainfall very much above average for the years 1976 and 1977. June 1977 shows exceptional rainfall when 219 mm (8.6 in) fell at the Zama lookout tower northeast of the town of Rainbow Lake.

The northern half of the map area falls within the discontinuous permafrost zone as indicated by Lindsay *et al.* (1960) and as indicated on the Geological Survey of Canada map "Permafrost in Canada" (1967). Ice was found at depths of about 0.5 m (20 in) (Lindsay *et al.*, 1960). The southern limit of the discontinuous permafrost zone in the area coincides roughly with latitude 59° north.

VEGETATION

Muskeg is present in most regions of the area, including some hilltops. Stunted trees are a common sight, except in areas of better drainage and where the water table is deep, as is the case on some hills in the southeastern part of the map area and also along the ridge located directly south of Zama-Hay Lakes. The main tree species are white spruce *(Picea glauca)* and trembling aspen *(Populus tremuloides)*. In their exploratory soil survey of the area, Lindsay *et al.* (1959) indicated that the soils of the Hay Lake Lowland are saline: "the Hay Lake area will be restricted to the growing of salt tolerant crops." In a year with average precipitation, salt deposits should be present on the ground in such an area; however, during the inundation of the spring and summer of 1977, salt deposition was not observed. Parts of the prairie in the area immediately surrounding Zama-Hay Lakes were also under water.

GEOLOGY

SURFICIAL SEDIMENTS

A general bedrock topography map of the area was constructed using seismic data, oil and gas well E-logs from oil companies, a few waterwell logs, core-hole logs, and bedrock outcrops. In general, the data available are not very detailed nor very accurate. The overall impression,

however, is that surficial sediments are thin in the southern part of the map area, thickening north of Zama-Hay Lakes. A short distance north of Zama-Hay Lakes a sand and gravel aquifer is exploited for water injection for secondary recovery of oil. The surficial sediments continue to thicken towards the northern part of the map area. Around Bistcho Lake, surficial sediments reach a maximum thickness of about 363 m (1200 ft), as reported in an oil company oil well E-log. In the southern part of the map area, the highs are bedrock controlled. In the northern part, the highs are composed of surficial sediments. Such is the case for the Bootis Hill, the unnamed hills found south of Bistcho Lake, and the Cameron Hills, all of which are composed of a mantle of surficial sediments, possibly up to 300 m (1000 ft) thick.

BEDROCK SEDIMENTS

The bedrock geology of northwestern Alberta and adjacent British Columbia and Northwest Territories has been investigated and described by the Alberta Study Group (1954); Law (1955); the Alberta Society of Petroleum Geologists (1966); Green *et al.* (1970); Pugh (1973); Thompson (1977); and Williams (1977). Some aspects of the bedrock geology have been described by the Energy Resources Conservation Board (1963) especially with respect to the Peace River oil sands.

As a rule, the hydrogeological map series investigate the geological and hydrogeological conditions to a depth of 300 m (1000 ft). This investigation, however, goes deeper in order to give a more detailed picture of the structure and geological sequence found in the area. Thick drift, particularly in the northern half of the map area, warrants deeper investigation. Structure contours on top of the Paleozoic surface, the Devonian, the Bluesky-Gething Formation, and the Base of the Fish Scales marker are given on the geological side maps.

All cross-sections terminate in Paleozoic sediments. In the southern and southwestern portions of the map area, the cross-sections terminate in sediments of the Mississippian period, which are mainly composed of limestone and shales. In the remainder of the map area, the cross-sections terminate in the Wabamun Formation of Devonian age, mainly composed of limestone.

A major unconformity separates the Paleozoic strata from the Lower Cretaceous strata. The sediments unconformably overlying the Paleozoic strata are those of the Bluesky-Gething Formation of Lower Cretaceous age. These sediments are mainly composed of sandstones, siltstones, shales, and coal. In the study area, the Bluesky-Gething Formation is 30 to 45 m (100 to 150 ft) thick. The sandstone strata of the formation disappear to the northwest, to be replaced by shales. Farther to the south in the Peace River oil sands area, "oil saturation occurs within the Bluesky Formation and the underlying Formation" (Energy Resources Conservation Board, 1963). In the study area, this formation produces gas.

In the map area, the Fort St. John Group includes the Loon River and the Shaftesbury Formations. The thickness of the sediments in this group varies greatly, from about 60 m to about 730 m (200 to 2400 ft). The marine Loon River Formation of Lower Cretaceous age is composed of shales and siltstones and its subcrop area is found in the central portion of the map area. The marine Shaftesbury Formation of Upper and Lower Cretaceous age is composed of bentonitic shales with silty and sandy intervals; the subcrop of this formation is found in most of the map area.

The overlying deltaic to marine Dunvegan Formation is found in the hills in the southern part of the map area. This formation is mainly composed of sandstones, siltstones, and shales.

HYDROGEOLOGY

PREVIOUS WORK

The only hydrogeological study available in the immediate vicinity of the map area is by Tokarsky (1972), which covers the region of Mount Watt southeast of the map area.

WATER LEVELS

Water level data are almost nonexistent for the entire map area. During the field season, over most of the region the water table was observed to be close to or at the land surface. The few water wells in the region are found a short distance north of Zama-Hay Lakes in the central part of the map area. All these water wells are completed in sands and gravels that are confined, with water levels near the land surface at a depth of about 5 m (17 ft).

A few flowing seismic shotholes, indicating upward groundwater movement, have been reported by oil companies. As a rule these flowing seismic shotholes are shallow, in the order of 20 m (65 ft) deep and indicate shallow upward groundwater movement.

The main discharge area is the large lowland of the Zama-Hay Lakes, which displays phreatophytes such as Juncus

and willows. Lindsay and Odynsky (1960) reported that the soils of this area contain large amounts of salts. During the field season, several smaller discharge areas were observed in particular, discharge meadows covered with phreatophytes, immediately to the east of Hay Lake. In some areas of these meadows, strong hydrogen sulfide emanations are found. Due to flooding of the Zama-Hay Lakes region, salt deposition was not observed. Northeast of the lakes, at the eastern boundary of the map area, a smaller deposition of salt ($NaHCO_3$ or Na_2SO_4) was observed within another large discharge meadow. After a heavy rain, these salts were washed away only to reappear after a period of dry weather.

Since the northern half of the map area is located in the discontinuous permafrost zone, at least locally, the recharge can reasonably be assumed to be reduced in areas of permafrost, especially in the Cameron Hills, the Bootis Hill, and the unnamed hills.

In the southern portion of the map area, the rate of recharge will be low, since surficial sediments are thin and the bedrock sediments are mainly composed of shales of the Fort St. John Group.

AQUIFER YIELDS

The map area contains five categories of aquifers. The Paleozoic sediments, which are composed mainly of carbonates, have saline (NaCl) groundwaters with total dissolved solids (TDS) in the range of 20 000 to 50 000 mg/L as inferred from various formation water analyses available (Energy Resources Conservation Board files). These groundwaters are currently of no practical value. The potential yield of Paleozoic sediments is unknown.

The Lower Cretaceous Bluesky-Gething Formation is water-bearing, but these waters are also saline; however, the quality of the groundwater in these sediments is indicated to be better than Paleozoic waters. Bluesky-Gething waters have a TDS content of less than 5000 mg/L compared with Paleozoic waters with a TDS content varying from 20 000 to 50 000 mg/L. The potential yield of this water-bearing formation is unknown.

The Fort St. John Group, consisting of the Loon River and Shaftesbury shales, has been attributed a yield range of less than 0.1 L/s (<1 igpm), although no yield value is available for these two formations. Sandy intervals may be able to produce slightly more water; however, water quality would be poor due to slow groundwater movement through low permeability sediments.

The sandstones of the Dunvegan Formation in the southern part of the map area have been attributed a yield range of 0.2 to 0.4 L/s (1 to 5 igpm), because they are not very thick. These sandstone are also located on high ground and are, therefore, possibly unsaturated.

The surficial sediments are the main aquifer over the study area. In the southern part of the map area, surficial sediments have been attributed a yield range of 0.1 to 2 L/s (1 to 25 igpm). This range was chosen considering the variation in thickness of unconsolidated sediment, which varies from 15 m, or less, up to about 100 m (50 to 350 ft), and also considering the impossibility of outlining the yield areas in more detail because of lack of data. Several dry holes were indicated along with some producing water wells.

The highest attainable yields known to date over the entire area are found in the northern half of the map area immediately north of the Zama-Hay Lakes region, where a few water wells are used for water injection in secondary recovery of oil. The water wells are completed in sands and gravels at depths varying from 30 to 60 m (100 to 200 ft). After completion, a few aquifer tests were conducted on these wells by a drilling company. Transmissivity values derived from these pump tests varied from about 37 m^2/day (2500 igpd/ft) to about 2240 m^2/day (150 000 igpd/ ft) with 20-year safe yields varying from about 15 L/s to 450 L/s (200 to 6000 igpm).

Table 1 shows transmissivities and potential 20-year safe yields in the surficial sediments found in that region north of Zama-Hay Lakes. The data are from drillers' records.

Farther to the north of this high-yield aquifer, there are no water wells; however, the thickness of the drift is known to vary from about 120 m to 360 m (400 to 1200 ft). A yield range of 2 to 8 L/s (25 to 100 igpm) has been adopted for the surficial sediments by analogy with other areas of the province where the thickness of the drift is similar and because one oil well E-log near Bistcho Lake indicates several zones of high permeability within the surficial sediments.

HYDROCHEMISTRY

Samples of hydrogeological features and surface waters were taken in a survey-by-helicopter during the field season of June and July 1977; 106 hydrogeological features and 104 surface water bodies were sampled. Two hydrochemical side maps were constructed using the results of the analyses of the water samples.

TABLE 1

Examples of Transmissivities and potential yields of the surficial sediments north of the Zama-Hay Lakes region (from Groundwater Division file)

Well Location Mer-Tp-R-Sec-Lsd Lsd-R-Tp-Mer	Aquifer Material	Aquifer Thickness	Length of Aquifer Test	Transmissivity	20–Year Safe Yield
02-12-05-110-W6	sand and gravel	13 m (40 ft)	17.5 hrs	247 m^2/day 16 583 igpd/ft	47 L/s 629 igpm
13-10-06-110-W6	gravel	13 m (40 ft)	12 hrs	0.7 m^2/day 47 igpd/ft	0.07 L/s 1 igpm
05-22-06-114-W6	sand	23 m (75 ft)	24 hrs	950 m^2/day 63 724 igpd/ft	379 L/s 5013 igpm
18-05-115-W6	sand and gravel	5 m (16 ft)	3 hrs (air lift)	281 m^2/day 18 876 igpd/ft	77 L/s 1011 igpm
01-28-05-115-W6	sand and gravel	23 m (75 ft)	72 hrs	2176 m^2/day 146 000 igpd/ft	461 L/s 6090 igpm
01-28-05-115-W6	gravel and coarse sand	19.5 m (64 ft)	72 hrs	320 m^2/day 21 500 igpd/ft	97 L/s 1279 igpm
14-12-06-116-W6	sand and gravel	13 m (43 ft)	24 hrs	39 m^2/day 2627 igpd/ft	15 L/s 193 igpm

(a) The surface waters include streams and lakes. In general, surface waters are fresh. The total dissolved solids contents (TDS in mg/L) vary from less than 50 mg/L to a maximum of 650 mg/L, the highest values being the exception rather than the rule; most TDS contents are within the range of 100 to 300 mg/L. Surface water TDS were not contoured, rather areas of ranges of TDS were outlined. Surface waters with the lowest (less than 50 mg/L) TDS are found in the southern part of the map area where drainage is relatively good. The northern parts of the area have TDS contents in the surface waters in the range of 50 to 100 mg/L. In this area, drainage appears to be fair and although streams are relatively fast, erosion is not readily apparent, so streams have a minimal sediment load.

Surface waters with the highest TDS content, ranging from 100 to 300 mg/L and over, are found in the central part of the map area. This area is the main lowland and also the main groundwater discharge area. Maximum TDS content of surface water is in the area directly south of the unnamed hills in the central part of the northern half of the map area. The central part is also the location where erosion was observed, where streams have a high sediment load, where surficial sediments are more clayey, and where bedrock sediments are closer to the land surface.

Surface waters are, without exception, of the calcium-magnesium type. The predominant anion is bicarbonate, with sulfate type of waters being the exception. Sulfate waters are found where the TDS content is the highest — in the main groundwater discharge area.

The weather conditions during the spring of 1977 led to flooding with subsequent erosion, and added large amounts of sediment to streams and other surface bodies, which may explain in part the higher TDS content as well as the presence of sulfates in the lower parts of the main drainage system.

(b) Groundwater samples collected during the course of the study were from springs, seepages, discharge meadows, and discharge ponds.

Again, note that excessive rainfall in the area in the spring and summer of 1977 may have diluted the groundwater chemistry and masked the groundwater phenomena. Since most samples collected are from surface features, the chemistry of these samples might not necessarily reflect the exact situation, but might only indicate general trends.

The TDS content of the groundwater ranges from less than 100 mg/L in the northern part of the map area to slightly over 3000 mg/L in the central part. The lowest values are found in the vicinity of Bistcho Lake. The TDS contours in that area, particularly southwest of the lake, suggest that water from the lake infiltrates into the surficial sediments possibly to resurge some distance away from the lake in a series of small lakes that eventually empty through small streams into the Petitot River.

Groundwater with the highest TDS content is found in the surficial aquifer a short distance north of Zama-Hay Lakes. The high TDS content of these waters is an anomaly because the permeable surficial sediments are shallow. One possible explanation is that these very permeable sediments are resting on bedrock shales of the Shaftesbury Formation in a discharge area with resulting high TDS content and a sodium sulfate type of water. The TDS content of the groundwater in the remainder of the area is 500 mg/L on the average, with lower values generally found on higher ground. A cold (1.3°C) spring, with a TDS content of about 1000 mg/L, deposits iron and calcium carbonate some distance south of Bistcho Lake. This spring is peculiar because it starts at the top of a mound of iron oxide about 5 m (15 ft) in diameter and 1 to 1.5 m (3 to 4.5 ft) in height. This is a very cold spring compared to other discharge features. The low temperature is probably due to the presence of permafrost in the vicinity, since this area is in the discontinuous permafrost zone. The iron in the spring probably originates in the drift.

In over half the map area (generally in the western portion), groundwaters are of mixed types such as calcium-magnesium, sodium-potassium, and bicarbonate-sulfate. The main discharge area, in the central part of the map area, has waters with sodium-potassium sulfate and calcium-magnesium sulfate types. Calcium-magnesium bicarbonate waters are found on some topographic highs in the northern and southern portions of the map area and also in areas having a low TDS content.

Hydrogen sulfide (H_2S) emanations are common in the map area and are found in association with what are called "red ponds" and "sulfur ponds." As a rule, these ponds are shallow and the bottom is made up of an organic muck on top of which there is a thin sheet of water. The color of the top portion of the organic muck varies from whitish and yellow to pinkish red, probably from the presence of a variety of sulfur bacteria. The origin of the H_2S is likely due to organic activity, mainly sulfur-reducing bacteria.

A few unusual water chemistries were encountered; waters with a variable TDS content ranging from 3.2 mg/L to 349 mg/L. All these waters were acidic with a pH of less than 4.5; the dominant type of water was either calcium or sodium nitrate. These waters were all found in the northeastern part of the map area and seem to be related to the presence of muskeg.

CONCLUSIONS

The Zama-Bistcho Lakes map area contains only one major aquifer, which is in the surficial sediments. Potential yields of this aquifer vary from 0.1 to 2 L/s (<1 to 25 igpm) in the southern portion of the map area to 15 to 450 L/s (200 to 6000 igpm) directly north of the Zama-Hay Lakes region. In this area, transmissivities up to 2176 m^2/day (146 000 igpd/ft) have been found in shallow gravel deposits. Groundwater quality of the main aquifer is good, with an average total dissolved solids content of about 200 to 300 mg/L and chemical types of calcium-magnesium bicarbonate to sulfate. Poorer quality of groundwater is found in discharge areas, particularly the Zama-Hay Lakes region, where calcium-magnesium sulfate groundwaters have a total dissolved solids content ranging from 500 to 3000 mg/L. Cretaceous bedrock sediments are composed of shales for the most part, with the exception of the Dunvegan sandstones of Upper Cretaceous age and the sandstones of the Bluesky-Gething Formation of Lower Cretaceous age. These sediments usually have a low yield potential. The yield potential of Paleozoic sediments is unknown and their waters are saline.

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Alberta RESEARCH COUNCIL

MAIN MAP LEGEND

TOPOGRAPHY
Surface contours and elevation in feet (interval 500 feet)

GEOLOGY
Geological boundary: defined; approximate

QUATERNARY
- Qd Unconsolidated deposits
- Qsg Sand and gravel

CRETACEOUS
- Ksh **Shaftesbury Formation**
- Blsc Base of the Fish Scales
- Kl Loon River Formation
- Kge Gething Formation

MISSISSIPPIAN
- Msh Shunda Formation
- Mpk Pekisko Formation
- Mbf Banff Formation

DEVONIAN
- Dwb **Wabamun Formation**

LITHOLOGY
Sand and gravel; Sandstone; Sandstone and shale; Shale; Limestone

HYDROGRAPHY
Lake or slough, perennial; Lake or slough, seasonal; Marsh, muskeg; Stream, perennial; Stream intermittent; Surface water divide; **Groundwater feature sampled**; **Surface water sampled**

HYDROGEOLOGY
Spring, flow rate unknown; Spring, flow rate in igpm (l/sec)

GROUNDWATER PROBABILITY
Range of average expected yield of wells in imperial gallons per minute (l/sec)

Possible: estimated from quantitative information (flow regime, lithology, etc.)

more than 500	(38)
100-500	(3-38)
25-100	(2-8)
5-25	(0.4-2)
1-5	(0.1-0.4)
1	(0.1)
1-25	(0.1-2)

Yield area boundary

†The indicated average expected yields to wells are predictions based on the best data available at the time of map compilation; due to the data shortcomings and special conditions, local discrepancies between predicted and actual yields are inevitable. Multiaquifer completion may be necessary to obtain the yield indicated.

WELLS AND OTHER ARTIFICIAL WORKS
DEPTH SCALE (FEET: 0, 100, 200, 300, 400) — Depth to water; Depth of well or seismic shot hole

Water well, nonflowing; Water well, flowing; **Water well, nonproducing**; Recharge well; Seismic shot hole; Oil well*; Gas well*; Suspended well*; Abandoned well*; Structure test hole*; Depth of exploratory well*; Storage reservoir; Dugout or borrow pit.

**The vertical line portion of oil, gas or other exploratory test well symbols indicate the well depth; the dashed portion indicates the surface casing interval where applicable or where known (otherwise, a solid line is used).*

Line of hydrogeological profile A — A′

HYDROCHEMISTRY
Calcium; Magnesium; Sodium + potassium; Carbonate + bicarbonate; Sulfate; Chloride; Nitrate (Cations | Anions)

Note: When the yellow Mg pie sector is absent Ca & Mg are represented as a unit by the red pie sector

Isogram along which calcium & magnesium constitute 60 percent of total cations ; teeth indicate direction of lesser calcium & magnesium content;
defined; **approximate**

Isogram along which sodium & potassium constitute 60 percent of total cations*, teeth indicate direction of lesser sodium & potassium content: defined; approximate

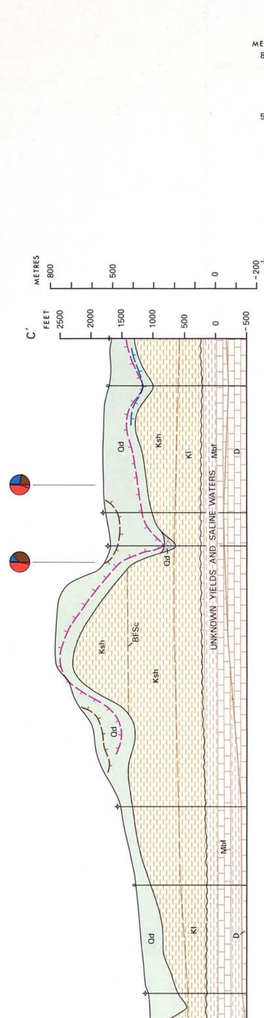
Isogram along which carbonate & bicarbonate constitute 60 percent of total anions*, teeth indicate direction of lesser carbonate & bicarbonate content: defined; approximate

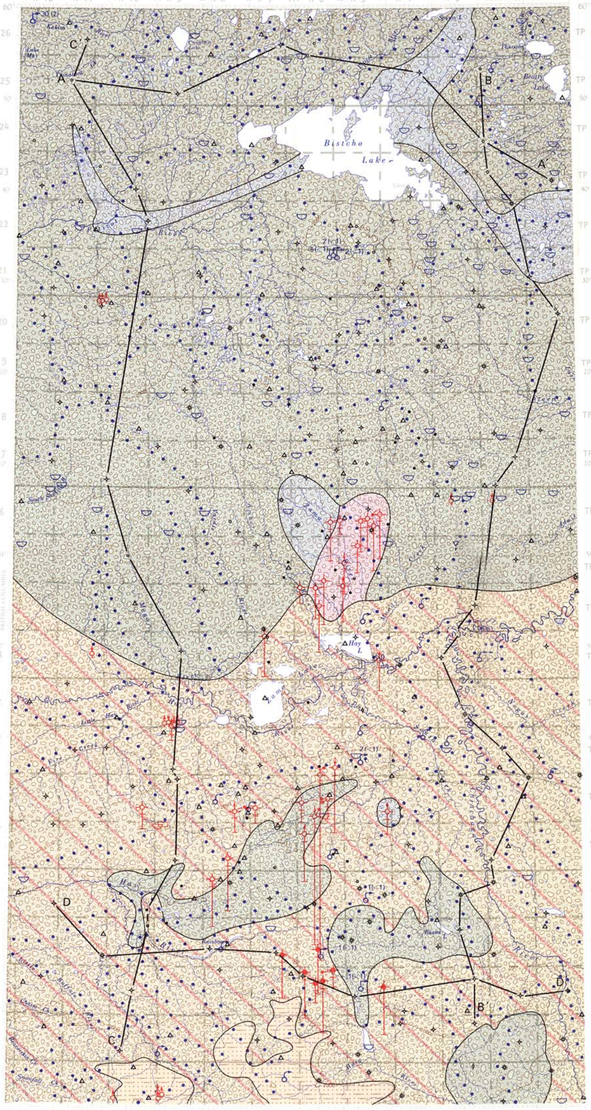
Isogram along which sulfate constitutes 60 percent of total anions*; teeth indicate direction of lesser sulfate content: defined; approximate

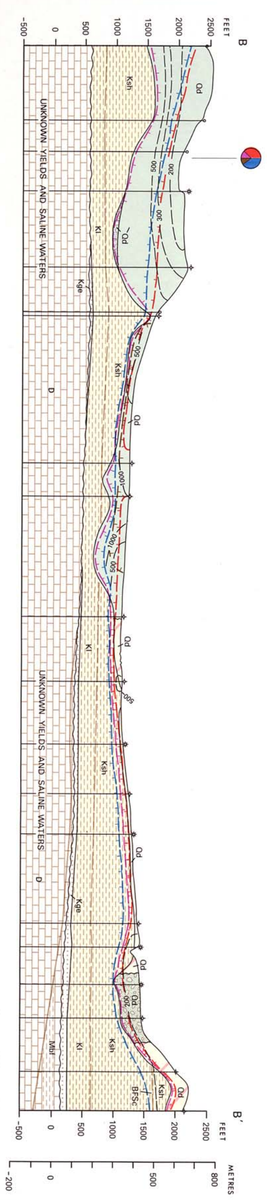
**Determined on equivalents per million basis.*

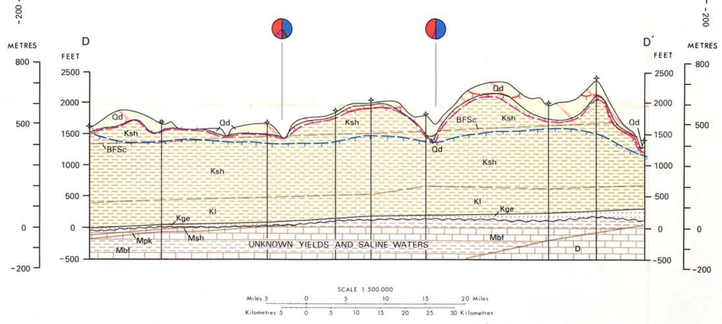
CONVERSION TABLE
LOGARITHMIC SCALE

FEET; METRES; IMP. GALLONS; U.S. GALLONS; LITRES; IMP. GALLONS PER MINUTE; CUBIC FEET PER SECOND; LITRES PER SECOND; CUBIC METRES PER DAY









All elevations in feet above mean sea level.

Vertical exaggeration of the hydrogeological profiles is approximately 40X.

An expanded legend and explanatory notes (Earth Science Report 72-12) for use with this hydrogeological map series is available from Alberta Research Council, Edmonton, Canada.

Map to accompany Earth Sciences Report 80-3.

Hydrogeology by D. Borneuf.

Drafted by R.W. Swenson.

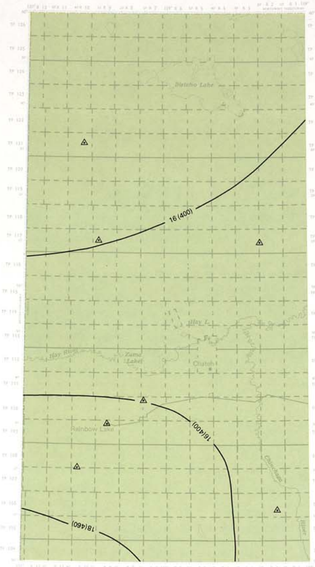
HYDROGEOLOGICAL MAP ZAMA–BISTCHO LAKES ALBERTA

NTS 84L–M

Base map provided by Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; modified by Surveys Branch, Alberta Transportation, Edmonton

Published in 1982

METEOROLOGY



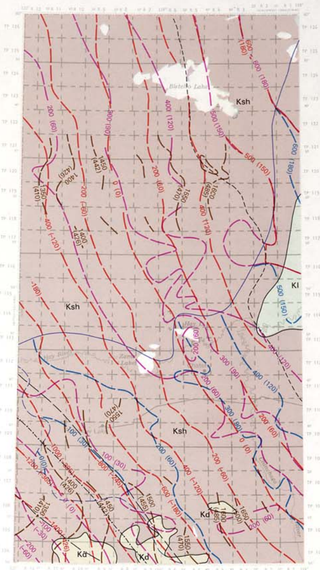
LEGEND

Isohyet, mean annual precipitation in inches (mm) — 16(400)

Mean annual precipitation in inches (mm)
15 to 20 inches (380 to 510 mm)

Forestry station

GEOLOGY



LEGEND

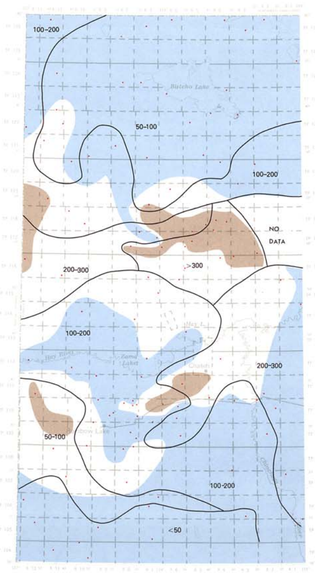
Dunvegan Formation: *gray, fine grained, feldspathic sandstone with calcareous beds; siltstone to shale beds; deltaic to marine* — Kd

Shaftesbury Formation: *dark gray, fish-scale bearing shale; numerous nodules and thin beds of concretionary ironstone; bentonite partings; thin silty to sandy intervals; marine.* — Ksh

Loon River Formation: *dark gray, fossiliferous, silty shale and laminated siltstone; nodules and thin beds of concretionary ironstone; marine.* — Kl

Rock unit boundary
Approximate erosional edge of Banff
Approximate erosional edge of Pekisko
Approximate erosional edge of Shunda
Approximate erosional edge of Debolt
Depositional edge
Line of change from sandstone to sandy shale
Structure contour on the top of the Base of Fish Scale marker — 1500(455)
Structure contour on top of the Wabamun (upper Devonian Formation — 200(60)
Structure contour on top of the Blueksky - Gething Formation — 300(90)
Structure contour on top of the Paleozoic Formation — 500(150)

HYDROCHEMISTRY: SURFACE WATER

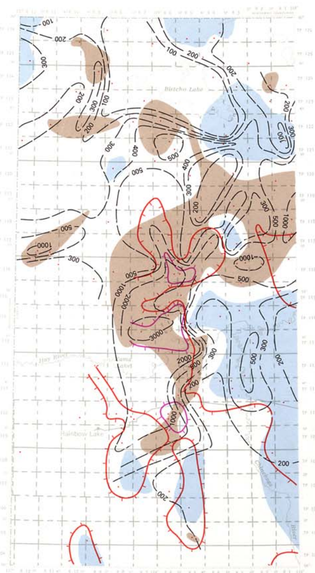


LEGEND

Surface water data point
Boundaries of total dissolved solids intervals (mg/L)
Surface water with Carbonate & Bicarbonate constituting over 60 percent of total anions*
Surface water with Sulfate constituting over 60 percent of total anions*
All surface waters have Calcium & Magnesium constituting over 60 percent of total anions*

**determined on equivalents per million basis.*

HYDROCHEMISTRY: GROUND WATER



LEGEND

Groundwater data point
Total dissolved solids (mg/l) — 300
Groundwater with Carbonate & Bicarbonate constituting over 60 percent of total anions*
Groundwater with Sulfate constituting over 60 percent of total anions*
Isogram along which Calcium & Magnesium constitute 60 percent of total cations*; teeth indicate direction of lesser Calcium & Magnesium content
Isogram along which Sodium & Potassium constitute 60 percent of total cations*; teeth indicate direction of lesser Sodium & Potassium content

**determined on equivalents per million basis.*